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REVIEW ARTICLE

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Management and sequelae of dental implant removal

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1 | INTRODUCTION

Contemporary implant dentistry has become embedded within a large number of dental practices around the world and is regarded by many as the panacea for a failing or failed dentition. Indeed, sophisticated implant macro-designs have been developed to deal with various and traditionally unfavorable case scenarios. Adell et al reported that approximately 20% of all implant failures arose in the posterior maxilla, whereas significantly more successful outcomes, expressed as implant survival rate, were achieved in the mandible.[1] Today, improvements in implant geometrical design, such as the incorporation of tapered implants, have resulted in more predictable outcomes in predominantly porous bone. Moreover, advances in material sciences have contributed to the development of modified fixture surfaces aimed at securing more rapid osseointegration with the goal of shortening treatment times. In fact, modern implant dentistry has grown and evolved rapidly, driven by consumer demand for immediate fixed tooth replacements. Frequently, the underlying reasons for tooth loss and their implications for replacement by dental implants are ignored, and a mechanical rather than a biological/biomechanical approach is adopted. This is an acute problem in patients who present with functional or esthetic issues caused by periodontitis, where teeth of questionable prognosis are considered for replacement by implants.

Recent meta-analyses have reported implant therapy to be effective and predictable.[2-6] Indeed, 5-year cumulative survival rates are reported to range between 90.5% and 100%, with an estimated failure rate of zero to two per 100 implants. Similarly, 10-year cumulative survival rates have been reported between 85.5% and 100%, representing an estimated failure rate of 0-1.56.[5] Similar outcomes have been reported in more complex scenarios, such as immediate or early implant placement simultaneously with guided bone regeneration.[7-9] However, implant survival is no longer regarded as an appropriate outcome measure of success; rather, a lack of technical/biological complications and patient satisfaction have emerged as the outcomes of choice. In this regard, it must be recognized that biological and esthetic complications of implant therapy are commonly reported.

Peri-implantitis is regarded as a chronic inflammatory condition induced by a bacterial biofilm in susceptible hosts.[10] The definition is based on composite criteria, including radiographic and clinical features such as progressive bone loss (plus/minus 0.5 mm), increased probing pocket depth, erythema, and bleeding on gentle probing with or without suppuration.[11] It has been demonstrated that peri-implantitis progresses in an accelerating and nonlinear manner.[12] Indeed, in an analysis of peri-implant bone defect severity and morphology, the most frequent finding was defects of moderate severity (approximately 50%), whereas those of mild severity were the least prevalent (approximately 10%).[13] Moreover, the morphology of such cases was characterized by defects involving two-thirds of the wall, with buccal plate bone loss being more pronounced than lingual plate bone loss. These data reflect the complexity of the management of peri-implantitis and the questionable prognosis of dental implants under such conditions.[13] In point of fact, peri-implantitis is the leading cause of implant removal, and it may affect patient reluctance to undergo future implant placement in the same clinic or with the same professional.[14]

In the era of modern dental implantology, as the effectiveness of dental implant treatment has increased, patient expectations have also increased. Patient-reported outcomes have become the primary criteria for assessing implant success. Satisfying esthetics in implant density requires the reconstruction to reflect the natural appearance of the lost dentition and the adjacent soft tissues in a harmonious manner.[15] This is a very challenging field of contemporary research that has focused upon attempting to satisfy patient expectations and demands in technically challenging situations.[16] Nevertheless, it must be recognized that trained prosthodontists are likely to be substantially more critical of their own work than their patients are, as evidenced by clinical trials using visual analog scales to assess such

outcomes.[17,18] Notwithstanding the importance of the prosthetic reconstruction of a sited implant, overall implant prosthetics are dictated largely by implant positioning. In other words, malpositioned implants arising due to inadequate communication between the surgeon and the prosthodontist are more likely to result in esthetic failures. For example, implants placed in the esthetic zone outside of the bony envelope have to be compensated by soft-tissue grafting and/or concave emergence profiles in order to satisfy esthetics.[19] Despite advances in the esthetics of pink porcelain, certain situations are unmanageable esthetically without implant removal, despite the fact that the implants have successfully osseointegrated.

Implant removal differs significantly from tooth extraction. First, the periodontal ligament is a dense fibrous tissue aimed at supporting the dental structure within the alveolus, providing mechanical properties for resisting masticatory loads such as compressive forces, amongst others.[20] It is also important to take into account socket preservation during tooth extraction and to minimize associated bone damage.[21-24] In contrast, implants are ankylosed within the alveolar bone, which means that there is neither the mechanoreception nor the elasticity provided by periodontal ligament fibers. Hence, dental implants cannot be luxated; rather, the bone-to-implant contact has to be physically broken down (Figure 1). The conventional approach to retrieve dental implants consists of a cylindrical trephine bur to explant the implant without rupturing the osseointegration itself but rather removing a fine core of the supporting bone. Recently, more conservative methods have been proposed based on the application of a so-called removal torque.

2 | CRITICAL BUCCAL BONE THICKNESS FOR FUNCTIONAL AND ESTHETIC SUCCESS

Implant failures due to poor esthetic outcomes or biological complications very often originate from implant malpositioning.[25] Implant placement is a traumatic event, and understanding bone metabolism is essential to understanding the concept of "critical buccal bone thickness." Implants placed in healing sites need to be engaged by sufficient buccal bone thickness to ensure that, once initial bone remodeling has taken place, the entire implant surface remains osseointegrated.[26] At such sites, the outer bone layer is predominantly cortical bone, whereas the central area of the alveolar crest is characterized by a cancellous architecture. It must be noted that the cortical bone primarily receives its blood supply from the periosteal surface and from the endosteum.[27] When a flap is raised to gain access for implant placement, the blood supply from the periosteum is compressed, which may in turn lead to necrosis due to suboptimal bone regeneration/repair. Hence, in scenarios where the buccal bone plate is thin, osteoclasts activated by the receptor activator of nuclear factor-κB ligand/receptor activator of nuclear factor-κB pathway may lead to buccal bone resorption following flap closure. This remodeling may lead to loss of buccal bone and subsequent breakdown of the overlying mucosa, thus exposing the implant surface to the oral cavity, facilitating colonization by the microbial biofilm and the development of a chronic infectious-inflammatory lesion.[28]

Clinical studies have demonstrated the translation of such biological changes into clinical pathology.[26,29] An early report in 2000 pointed out that successful bone coverage of implants relied not only upon bone structure, but also a minimal buccal bone thickness of 1.8 mm in order to achieve successful outcomes.[26] This observation has been confirmed by others. Barone et al reported more favorable outcomes in the presence of at least 1 mm of buccal bone plate thickness.[29] Likewise, Covani et al[30] observed that in an adequate alveolar bone crest, the magnitude of bone resorption following implant placement in a healed socket was approximately 3 mm. In contrast, a recent study has demonstrated adequate peri-implant crestal bone levels with implants placed in limited buccolingual alveolar bone (up to 4.5 mm) during 3 years of loading.[31]

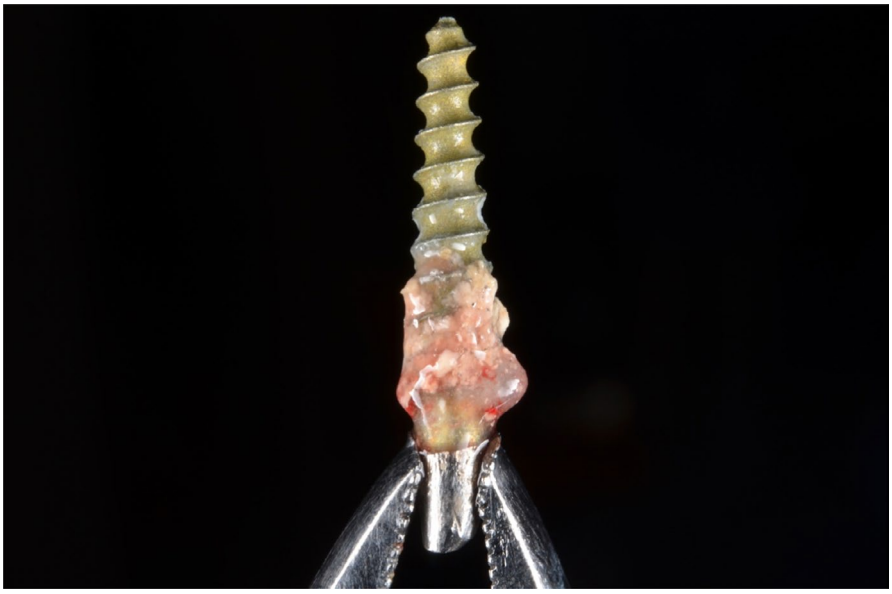


FIGURE 1 Implant removed using forceps by means of unscrewing motion to break the bone-to-implant connection

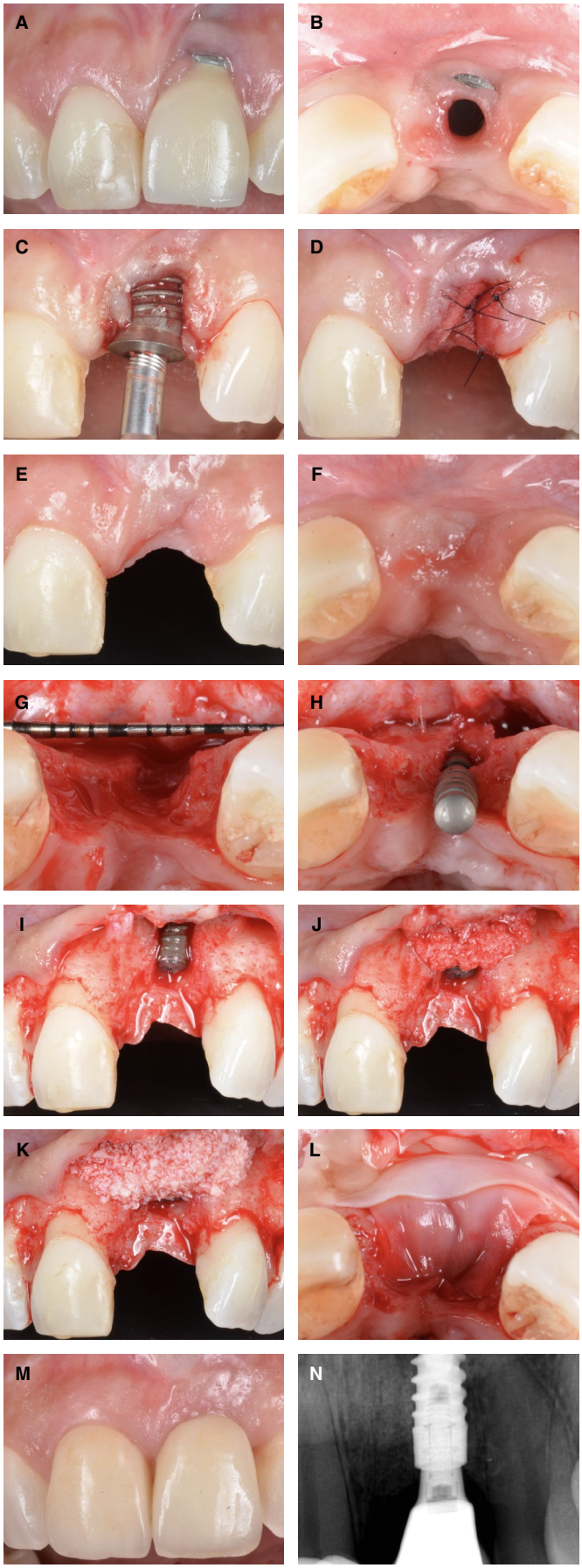


FIGURE 2 Esthetic implant complication. A, Bone dehiscence associated with inadequate implant position and thin mucosal phenotype led the case to an esthetic failure (frontal view). B, Occlusal view after crown removal. C, Implant removal was cautiously executed using reverse torque. D, Collagen matrix (Mucograft; Geistlich Pharma, Wolhausen, Switzerland) was used to seal the socket. No bone substitute material was used for grafting. E, Frontal view 8 weeks after implant removal. E, Frontal view 8 weeks after implant removal. F, Occlusal view 8 weeks after implant removal. G, Surgical entry 8 weeks after implant removal. Note the three-wall defect that may enable the achievement of primary stability and where hard and soft-tissue grafting are encouraged for successful esthetic outcomes. H, Occlusal view of reference pin used during implant placement. I, Implant was placed in the adequate three-dimensional position to achieve optimal esthetic outcomes. J, Autogenous bone harvested from the neighboring alveolar bone was used as grafting material combined with, K, slow resorbable bone substituted (Bio-Oss; Geistlich Pharma, Wolhausen, Switzerland). L, Resorbable membrane was used to fulfill cellular occlusivity (Creos xenoprotect; Nobel Biocare AG, Kloten, Switzerland). M, Clinical and, N, radiographic stability was noted 12 months after implant placement

A histomorphometric and clinical experimental study in dogs provided some insights into the dynamic process of buccolingual peri-implant bone remodeling 8 weeks following implant placement.[32] The authors reported that when thick buccal bone (greater than 1.5 mm) was present, the vast majority of histomorphometric variables remained more stable when compared with scenarios in which thin buccal bone was present (less than 1.5 mm). In a separate part of the study, a ligature-based model was employed to test the hypothesis that implants placed in thin buccal bone are at higher risk of developing more severe forms of peri-implant disease. In fact, it was noticed that implants placed in the presence of thick buccal bone (greater than 1.5 mm) are more effective in compensating the dimensional changes that arise during the progression of peri-implantitis. Peri-implantitis progressed in a more aggressive fashion with implants placed less than 1.5 mm from the buccal flange.[32] It is important to recognize that ligature models provide some insights into natural pathology, but they are acute models of peri-implantitis and may not directly translate to the natural human disease, which is chronic in nature. Given the multiple variables that contribute to the development of peri-implantitis, the effect of a "critical buccal bone thickness" upon the peri-implant tissue characteristics was also investigated. Unsurprisingly, more profuse bleeding on probing ($P = 0.01$), greater mucosal recession ($P = 0.001$), and increased suppuration ($P = 0.01$) were recorded in the presence of thinner buccal bone (less than 1.5 mm). Therefore, it was concluded that a buccal bone thickness greater than 1.5 mm appears to be more effective in compensating for the dimensional changes arising following implant placement and during the progression of peri-implantitis. Hence, simultaneous guided bone regeneration may be advocated in those scenarios where the integrity of the buccal bone cannot be guaranteed following physiological bone remodeling. These findings are very relevant for the prevention of esthetic and functional failures within implant dentistry.

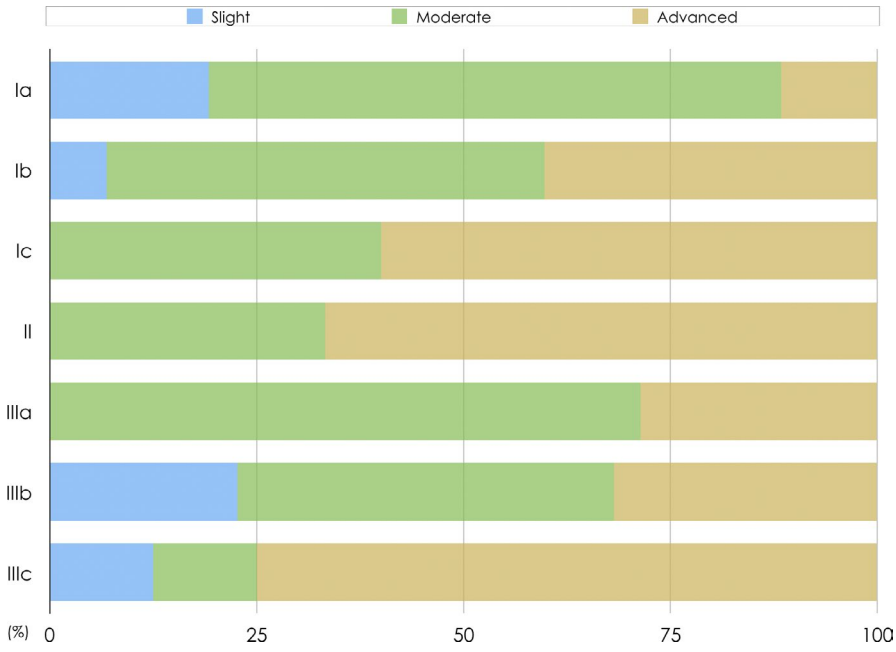


FIGURE 3 Severity of peri-implantitis according to the morphological features. Class Ia: dehiscence defect; class Ib: 2/3-wall defect; class IIIc: circumferential defect; class II: horizontal defect; class IIIa: horizontal plus dehiscence defect; class IIIb: horizontal plus 2/3-wall defect; class IIIc: horizontal plus circumferential defect. Mild: <25% of the implant length; moderate: ≥25%-50% of the implant length; severe: ≥25%-50% of the implant length

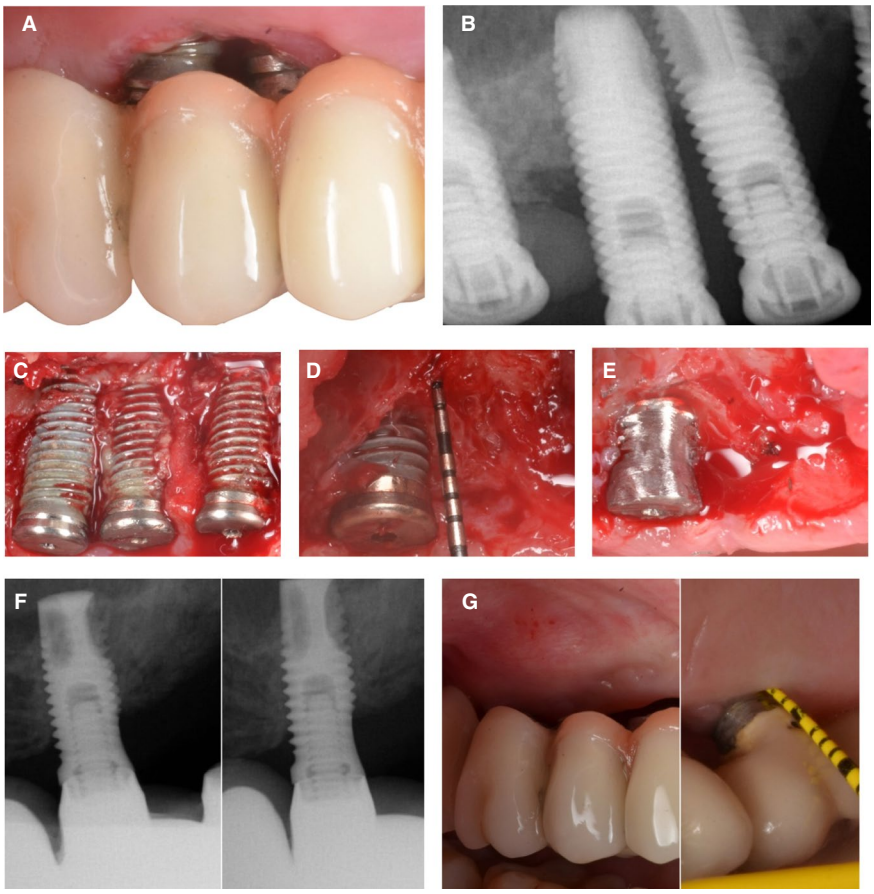


FIGURE 4 Failing implants due to cluster peri-implantitis within the same sextant. A, Clinical view of peri-implantitis affecting implants within the same sextant, supporting a fixed partial denture. B, Periapical radiograph where the unfavorable/hopeless prognosis is displayed due to severity and extension. C, Intrasurgical image of severe bone loss around the implants. D, The implants with the most severe form of peri-implantitis were removed due to their hopeless prognosis. E, The distal implant was treated by means of implantoplasty and an apically positioned flap to support the fixed dental prosthesis as a palliative (temporal) treatment. F, Radiographic follow-up at 12 and 24 months showing stable bone levels. G, Clinical image showing access to cleaning, free from peri-implant disease and with adequate function

3 | IMPLANT REMOVAL DUE TO ESTHETIC FAILURE

3.1 | Scope of the problem

Discrepancies between the soft-tissue contour, color, and the restoration margin are common causes of esthetic failure.[33] This type of complication is frequently associated with inadequate surgical performance, especially in technically demanding interventions such as immediate implant placement, where there is a tendency to shift the preparation of the implant bed toward the buccal aspect of the ridge.[34] This has also been observed with implants placed into healed alveolar ridges, on the assumption that the surgeon is attempting to minimize injury to anatomical boundaries, such as

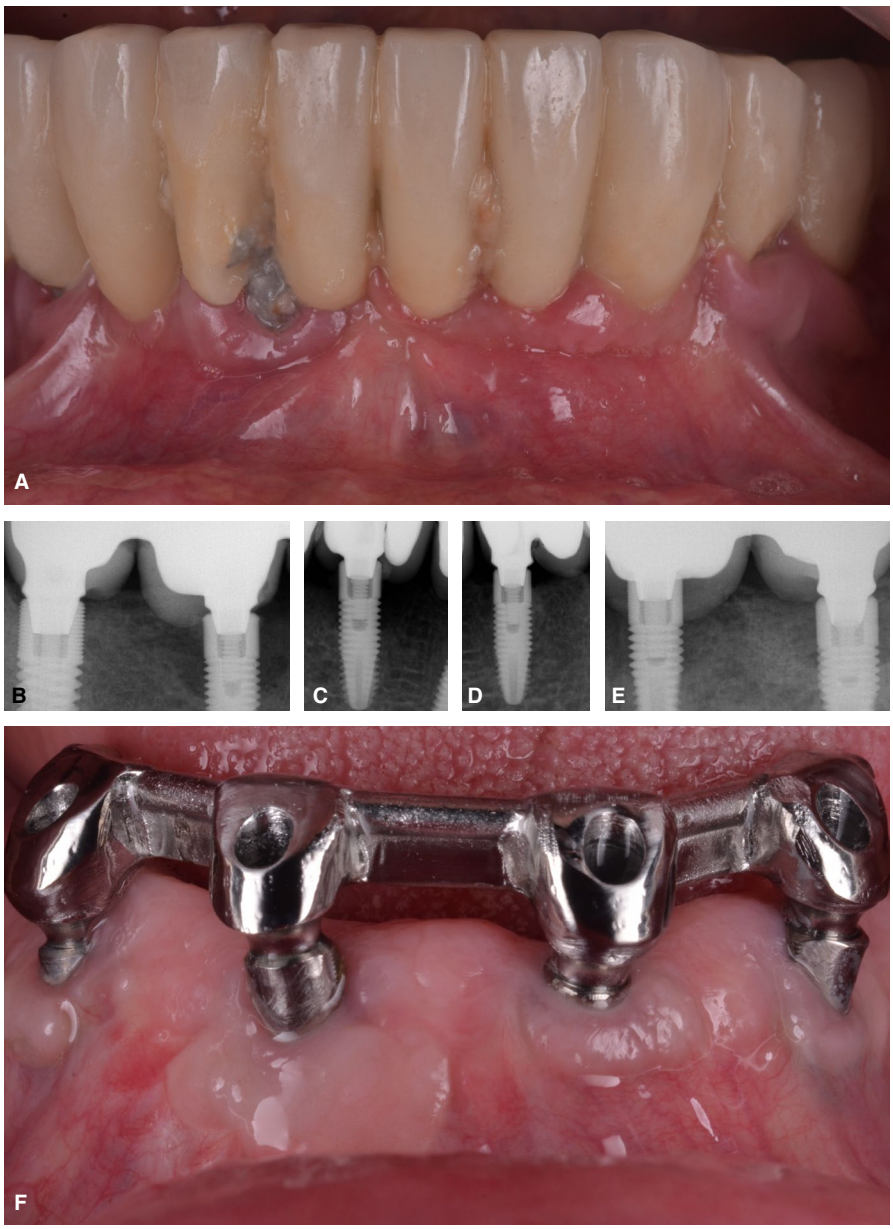


FIGURE 5 Multiple implants exhibiting peri-implantitis. A, Baseline scenario exhibiting peri-implant inflammation associated with the inadequate fixed prosthesis design, lack of keratinized mucosa in the anterior implants, and abundant plaque. B-E, Peri-apical x-rays indicate advanced bone loss in posterior implants and moderate bone loss in anterior implants. F, The 18-month follow-up after multiple implant removal due to advanced forms of peri-implantitis and implantoplasty as adjunct measure of soft-tissue conditioning by means of free epithelial graft with implantoplasty for the resolution of peri-implant inflammation. Note that the fixed prosthesis was replaced by an implant-retained overdenture that facilitated self-performed oral hygiene and monitoring

the mandibular concavity.[25] In line with the concept of a "critical buccal bone thickness," implants should be placed greater than 1.5 mm from the buccal bone plate.[32] Wherever this cannot be guaranteed, guided bone regeneration simultaneously with implant placement should be undertaken to limit the remodeling process. In addition, recent reports have stressed high rates of esthetic complications during immediate implant placement, due to midfacial recession and instability of the mucosal margin over 5 years of follow-up.[35] Hence, in such scenarios, it appears that it may be insufficient to compensate the dynamic bone remodeling changes through adequate implant position and, furthermore, that hard and soft-tissue augmentation procedures are needed to secure satisfactory esthetics.

The causes of esthetic failures include black hues/shades as a consequence of a dehiscence or fenestration-type defect exposing the grey implant surface to the translucent mucosa, and in particular in the presence of a thin mucosal phenotype or mucosal recession (ie, apical migration of the mucosal zenith) due to inadequate buccolingual and apico-coronal implant positioning or incorrect implant angulation (Figure 2). Moreover, esthetic failures due to the loss of papilla are observed as a result of inadequate mesiodistal implant positioning. Although some scenarios can be compensated with soft-tissue management/grafting and the implementation of prosthetic strategies, certain conditions preclude conservative approaches and necessitate implant removal. These are the most complex scenarios to manage, for three reasons:

1. Patients often demand high levels of esthetic outcome, and the esthetic complications are not necessarily associated with pathology.
2. Implant malpositioning frequently leads to one or two wall defects. To prevent this, immediate implantation is not advised due to the lack of feasibility of achieving primary implant stability.

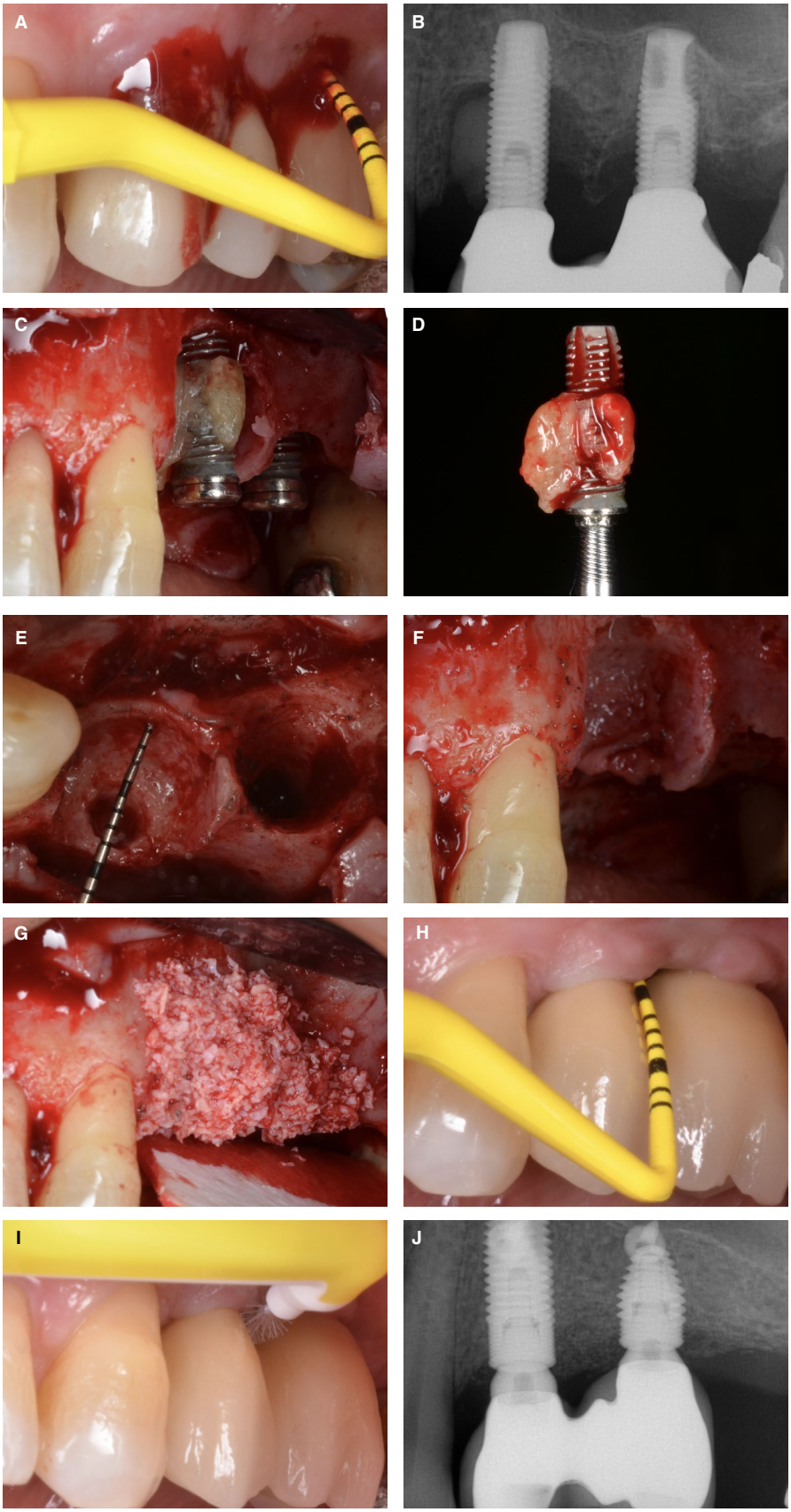


FIGURE 6 Simultaneous guided bone regeneration at advanced peri-implantitis site. A, Clinical and, B, radiographic assessment indicated advanced peri-implant bone loss as a consequence of peri-implant infection. C, Intraoperatively, advanced bone loss was identified. D, Implants were removed using reverse torque. E, Occlusal and, F, frontal views showing the large alveolar bone defect. G, Simultaneous guided bone regeneration using slowly resorbable bone substitute (Bio-Oss; Geistlich Pharma, Wolhausen, Switzerland) combined with autogenous bone and a resorbable barrier membrane (Creos xenoprotect; Nobel Biocare AG, Kloten, Switzerland) was carried out. H, I, Clinical assessment indicated health 12 months after implant placement. J, Bone stability at 12-month follow-up

TABLE 1 Methods and techniques proposed for removing failing dental implants

Technique	Invasiveness	Time consuming	Pros	Cons
Trephine burs	+++	−	Effective Fast	Difficult to perform immediate implant placement Very invasive for soft and hard tissues
Reverse torque	−	+	More conservative with hard and soft tissues Immediate implant placement is feasible Simplicity	Specificity for the different implant systems and macro-geometries Time-consuming
Electrosurgical and laser-assisted devices	++	+++	Relatively conservative with hard tissues	Time-consuming Difficult to perform immediate implant placement
High or low-speed rotatory burs	++	++	Effective to remove bone Efficient to remove the cortical portion in case of initial failure of less invasive techniques	Time-consuming Difficult to perform immediate implant placement
Forceps	++	+++	No overheating Effective for implants with severe bone loss	Fracture and implant deformation are often It might be used in combination with the use of rotatory burs

3. Scenarios where there are deficiencies of the hard and/or the soft tissues. Hence, hard and soft-tissue grafting are encouraged.

3.2 | Clinical management

Clinical management strategies require assessment of defect morphology and extent, and of the quantity and quality of available soft tissue. In such cases, immediate implant placement is not advised, regardless of the type of defect involved. Hence, it is preferable to use minimally invasive methods to retrieve the implant and to delay its replacement. If the scenario involves a two to three-wall defect where the buccal wall is not completely absent, the surgeon can opt to combine flapless bone regeneration following implant removal or, instead, allow for spontaneous healing. Whereas the first approach requires a suggested healing time of at least 4 months, in the second case an implant can be inserted earlier with simultaneous guided bone regeneration (Figure 2). With either option, corticotomies are advocated owing to the nature of the bone at the retrieved implant site, with limited vascularity. On the other hand, one or two wall defects resulting from removal often need flapped staged bone regeneration surgery with a healing period of at least 4 months prior to implant placement in an adequate position. Caution must be exercised in esthetic failure cases, as the drilling will tend to shift toward the previously failed implant site due to the mature compact bone, with few marrow spaces found at such sites.[36]

In the scenarios described, the need to enhance esthetic outcomes by augmenting soft-tissue thickness by means of free or pedicle connective tissue graft should be considered. This can compensate the bone deficiency in certain cases with more severe resorption.

4 | IMPLANT REMOVAL DUE TO PERI-IMPLANTITIS

4.1 | Scope of the problem

Peri-implantitis is unfortunately not an uncommon finding, with epidemiological studies suggesting a prevalence of approximately 18% when expressed at a patient level and approximately 12% when expressed at the implant level.[37] However, prevalence at patient level is reported to range broadly between 1% and 47%.[38] The nonlinear accelerated and progressive pattern of bone loss in peri-implantitis leads to implant failure if the disorder is not adequately dealt with and corrected.[12] Nevertheless, the efficacy of different interventions for peri-implantitis still remains a subject of debate, owing to poor predictability in the long term.[39,40] Hence, implant removal is often the treatment of choice to deal effectively with peri-implantitis. Based on the case definition proposed by Workgroup 4 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and

Potential complications								
Overheating	Implant fracture	Emphysema	Access	Visibility	Limitations	Speed (rpm)	Reverse torque (N cm)	Frequency (kHz)
X					Proximity to anatomical boundaries Long implants anchored in proximity of the floor of the mandibular body	1200-1500 (with copious saline irrigation)	—	—
	X				Narrow implants (<4 mm) Altered implant neck (fracture) More difficult for external connection implants	—	<250 (with saline irrigation)	—
			X	X	Access Visibility	—	—	20-40 (with copious irrigation)
X		X	X	X	Access Visibility	Low-speed: 800-1000 High-speed: 20 000	—	—
	X		X	X	Long implant anchored in proximity of the floor of the mandibular body Peri-implant severe bone loss to allow adequate anchorage	—	—	—

Conditions,[41] moderate or advanced forms of peri-implantitis are observed in about 90% of cases, with 50% of bone defects exposing between 25% and 50% of the implant length and 40% exposing greater than 50% of the implant length (Figure 3).[13] This implies an unfavorable prognosis for many peri-implantitis lesions subjected to palliative therapy such as resective or reconstructive procedures.

4.2 | Clinical management

Peri-implantitis lesions are often less demanding in terms of esthetic considerations, unless they arise in the anterior maxillary region. Accordingly, management options are broader. Clinical data suggest that advanced peri-implantitis lesions (50% or more) have a poorer therapeutic prognosis than less severe lesions do. Therefore, it is recommended that defects exceeding 50% of the total length of the infected dental implants should be removed.[42-44] A preclinical study in the dog evaluated the feasibility of reimplantation of dental implants retrieved following ligature-induced peri-implantitis.[45] In that study, the method for implant removal involved counter-rotation with a ratchet. Interestingly, it was found that by using wider dental implants to achieve primary stability following implant removal (50%), bone-to-implant contact did not differ significantly from bone-to-implant contact reported in implants placed in pristine bone (51%).[45] These findings were consistent with those of a previous study that evaluated the effect of three different detoxification methods following plaque accumulation upon osseointegration (bone-to-implant contact). The results from this study demonstrated that osseointegration may recur at implant surfaces (TiUnite) that were previously contaminated but subsequently detoxified.[46] Additionally, clinical findings indicate the success of immediate implant placement following the removal of implants from peri-implantitis sites: success rate, approximately 94%; marginal bone loss, approximately 0.9 mm; follow-up after loading, approximately 30 months.[47] The strategy used by the authors was based on the placement of wider implants compared with the socket dimensions following drilling, which may potentially contribute to mechanical decontamination of the socket. Moreover, it must be noted that, in the majority of the cases, grafting interventions were carried out to overbuild the implant site.[47] Indeed, Machtei et al, in a multivariate analysis, demonstrated that replacement of failed implants with longer and wider fixtures led to marginally improved survival ($P = 0.06$) compared with implants that were smaller than the previously failed implants.[48]

Thus, it appears that, provided the failing peri-implantitis implant is not malpositioned, immediate implant placement following widening of the socket may be a viable option. However, it should be noted that such scenarios are likely only feasible for mild peri-implantitis (less than 25% of implant length). Otherwise, in order to achieve primary stability, and given that the coronal portion of bone has resorbed as a consequence of the infection, positioning of the replacement implant may be too apical, resulting in detrimental

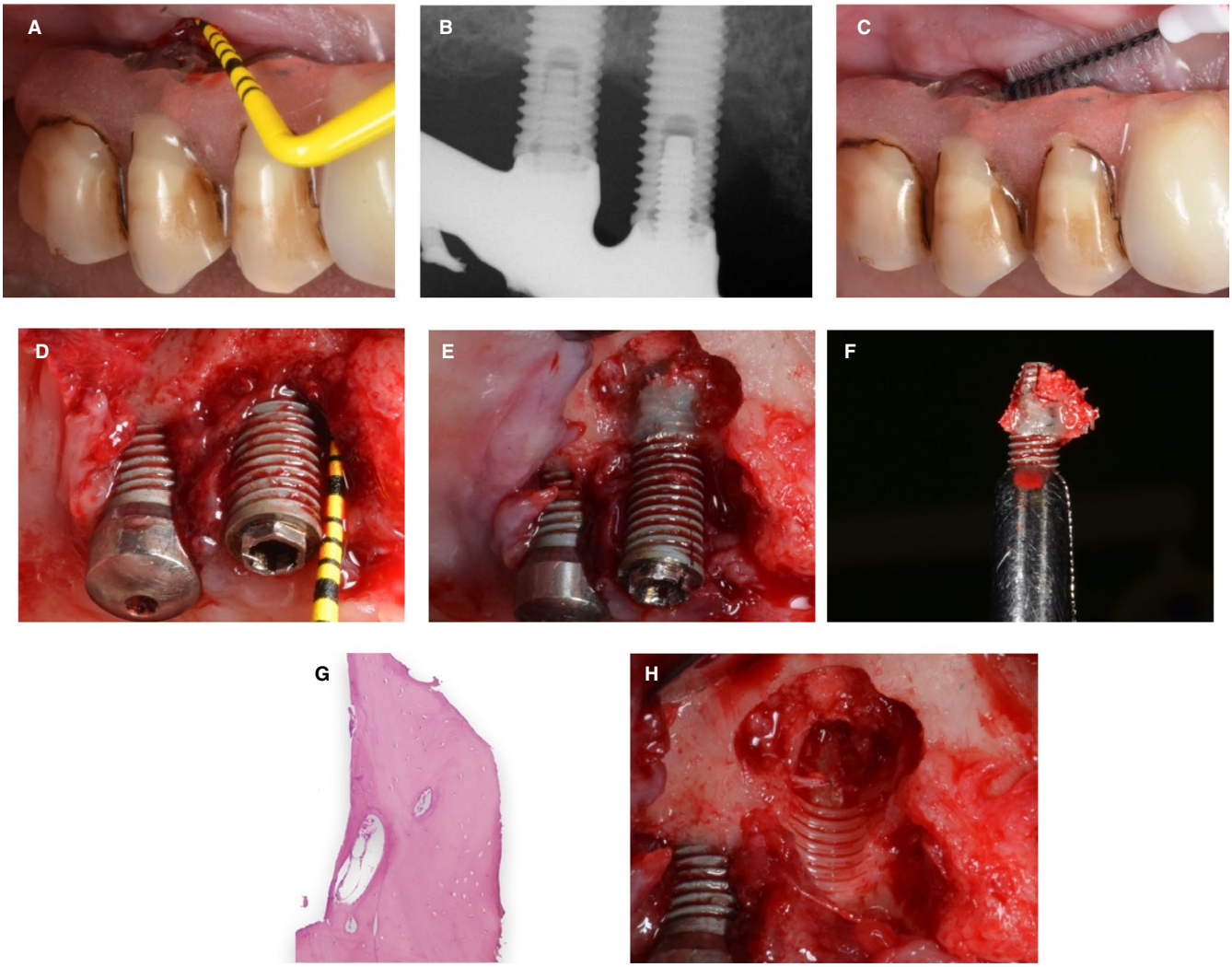


FIGURE 7 Implant removal due to peri-implantitis associated with a fixed prosthesis that precluded personal oral hygiene. A, Lateral view of the diseased site. Note increased probing pocket depth and profuse bleeding on probing. Bleeding is persistent after probing. B, Radiographic findings align with the clinical signs. C, Inadequate access for cleaning led to peri-implant disease. D, Combined bone defect morphology is illustrated after flap reflection. E, Owing to implant fracture at the coronal portion, extraction was carried out by resecting the buccal alveolar cortical bone to allow implant removal with forceps. F, Implant removal immediately after explantation. Note that this is a less invasive method. An osseointegrated bone fragment is attached to the implant. G, Histological sample of the ankylosed bone in the apical portion of the implant. Note the osteocytes within the lacunae in lamellar bone. H, Note in detail the bone defect and the print left by the threads

implant outcomes. Kumar et al[49] demonstrated that implant placement at a depth of 6 mm or more from the cemento–enamel junction of the adjacent tooth is more frequently associated with peri-implantitis (odds ratio 8.5). Hence, immediate implant placement following implant removal in moderate to advanced defects carries significant risks and is not advocated. For these scenarios, bone grafting simultaneous to implant removal has proven beneficial in terms of ridge preservation.[50] Moreover, in such cases the clinician should consider the restorability of the infected implant. If a fixed implant-supported partial/complete denture supported by the adjacent healthy implants can efficiently rehabilitate the edentulous site, then it might be advisable to focus treatment options on preventing peri-implantitis of the surviving implants (Figure 4). In these scenarios, it is suggested to consider shifting from a fixed prosthesis to an implant-retained removable prosthesis to facilitate monitoring and oral hygiene measures (Figure 5). In contrast, in cases where the failed implant is crucial to restoring oral function, the clinician may opt to graft the surgical site, followed by a healing period of at least 4 months prior to reevaluation. It is recommended that in cases of one or two missing walls and minimal infection, consideration should be given to the simultaneous use of a barrier membrane to improve bone gain and to fulfill more efficiently the principle of compartmentalization or to use block grafts to compensate the dimensional changes (Figure 6). These cases are only feasible when flap closure is achievable, otherwise a staged approach is recommended. In the most severe cases (one or two wall defects), longer healing periods are recommended to allow for the maturation of newly formed solid and lamellar bone.

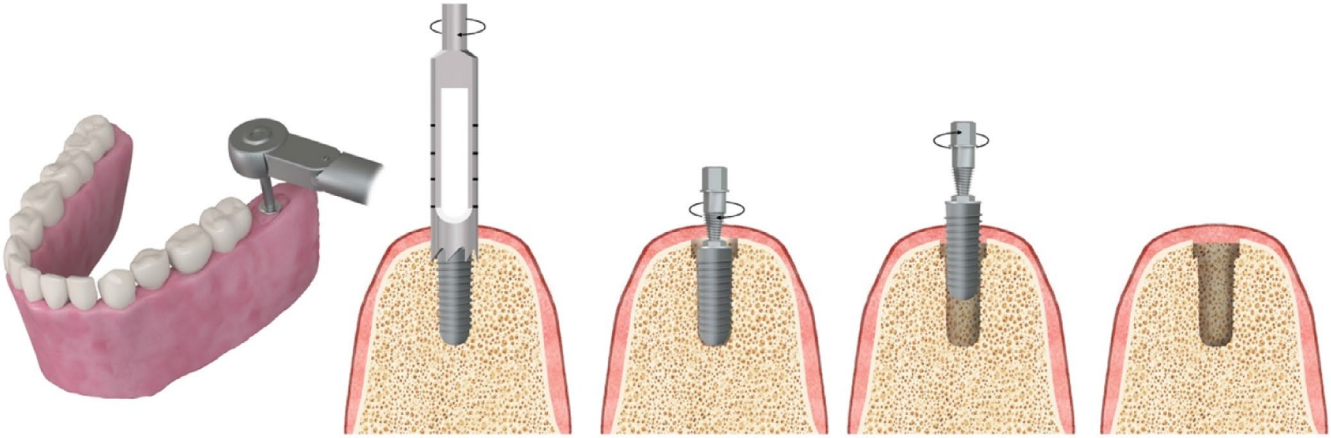


FIGURE 8 Minimally invasive system for removing implants failing due to esthetic or functional reasons. Note that the use of a trephine might be indicated to remove the cortical bone to facilitate later implant removal with a wrench (adapted from Anitua et al 2016)

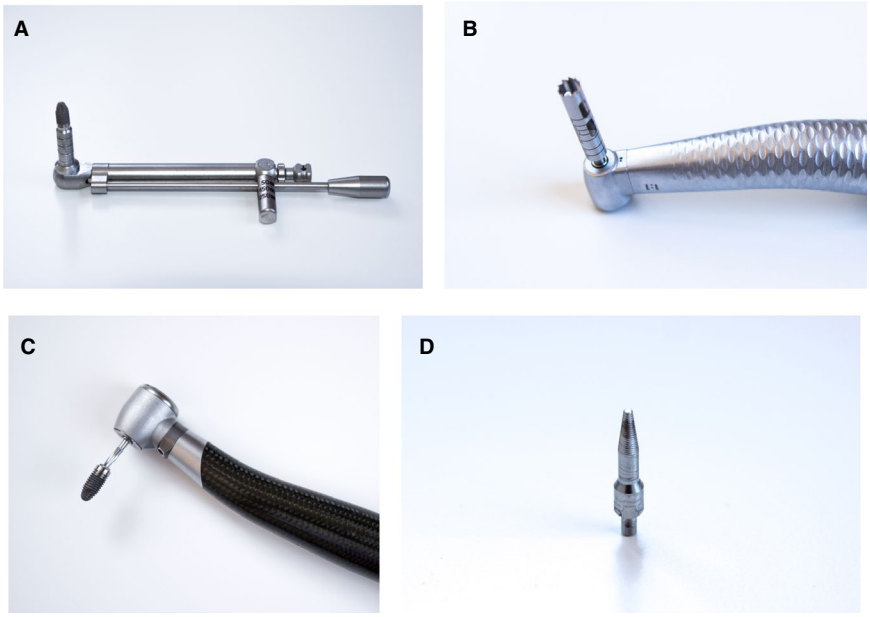


FIGURE 9 Implant removal kit (TICARE, Valladolid, Spain). A, Wrench connected to the implant neck to be used as the method of choice in unbroken implants. B, Trephine that should be used in situations where the cortical portion of the bone is to be resected to facilitate minimally invasive implant removal with removal torque, or in situations where the implant is broken. C, Bur to mold the internal connection in broken implants to secure implant removal. D, Implant removal device

These complex scenarios normally require a staged approach after spontaneous soft-tissue healing. In contrast, for four wall defects, the clinician could opt for flapless simultaneous grafting to minimize invasiveness at the implant placement stage, or a graftless and flapless procedure including curettage and corticotomies to boost the vascular supply may shorten the timeframe between implant removal and implant replacement. In these scenarios, simultaneous grafting at the stage of implant placement is frequently required. Hence, the former option is more advisable in these situations. Moreover, in scenarios characterized by multiple implant failures within the same sextant, the clinician could opt for staged vertical ridge augmentation or the use of short dental implants. Though the former is technically demanding, the latter is also not without technical complications that may originate from undesirable crown-to-implant ratios.

The presence of keratinized mucosa around dental implants is desirable to prevent the occurrence/recurrence of biological peri-implant complications;[8,11-51] therefore, soft-tissue grafting should be contemplated in cases of deficient keratinized mucosa of the buccal peri-implant site.[52-54]

5 | IMPLANT REMOVAL DUE TO FRACTURED IMPLANTS OR COMPONENTS

5.1 | Scope of the problem

Fracture of implant fixtures or components is rare, with implant facture being estimated to arise in less than 1% of cases.[55] Potential causes of implant fracture include inadequate fit of the superstructure or design characteristics of the fixture material, long-term metal fatigue, magnitude of occlusal forces, parafunctional habits (ie, bruxism), implant macro-geometry, and implant support.[56] Hence, biomechanical overloading seems to play an important role in implant fracture. It has been reported that approximately 90% of implant fractures arise in the premolar-molar

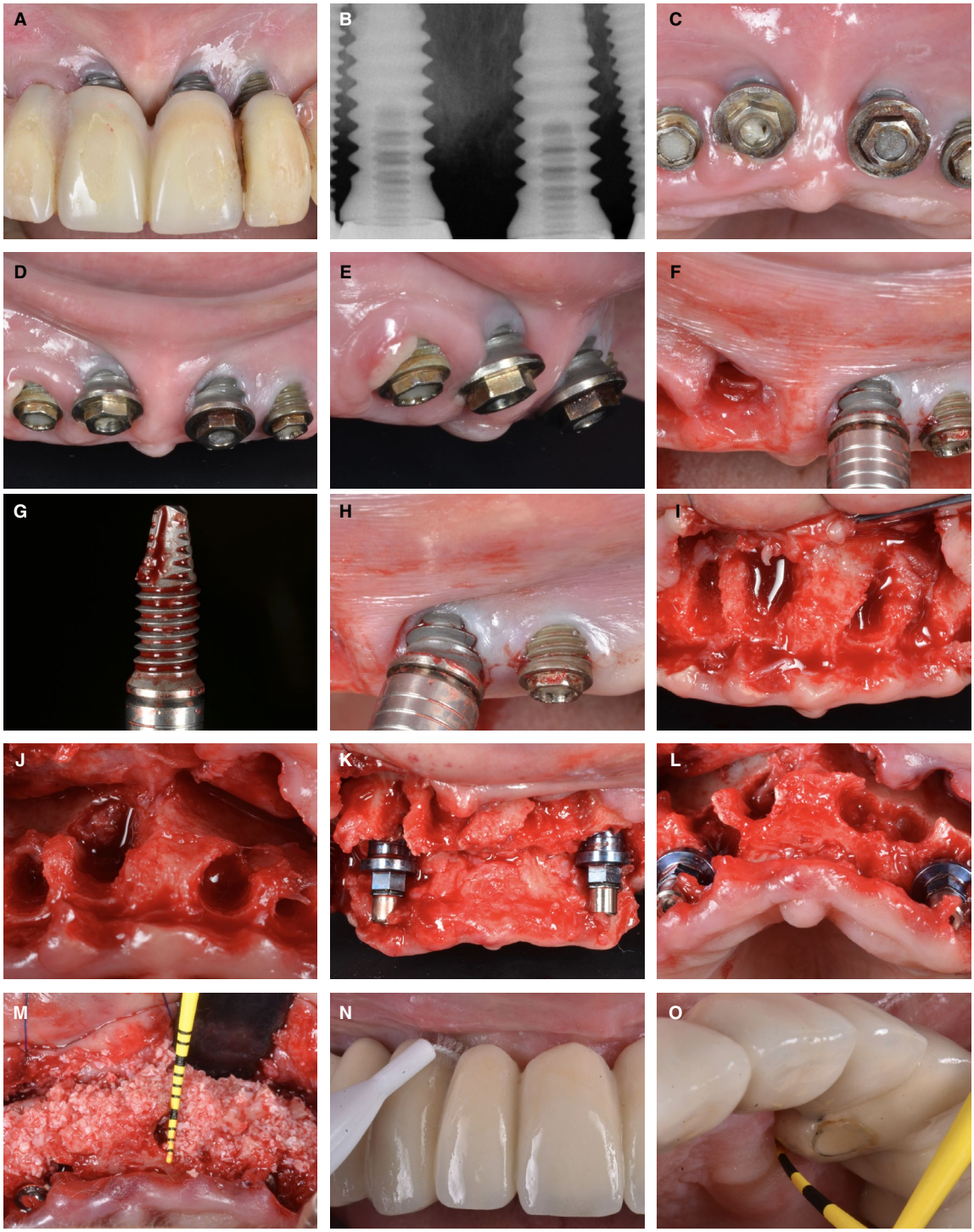


FIGURE 10 Esthetic implant failure case. A, Esthetic implant failure of anterior maxillary implants due to inadequate positioning/angulation, leading to bone dehiscence and mucosal recession. B, Bone loss secondary to inadequate implant placement. C, Occlusal view after prosthesis removal. D, Buccal view after implant removal. Note that, as a consequence of inadequate implant placement, implant #12 developed infection, as spontaneous suppuration and bleeding are present. E, Lateral view of the implants after prosthesis removal. Note the inadequate implant angulation. F, Flapless minimally invasive implant removal applying a removal torque of less than 100 N cm. G, Implant removed immediately after explantation. H, Implant removal system applying removal torque with a wrench. I, A flap is raised to evaluate the defect morphology in an attempt to offer alternative treatment to restore oral function and esthetics. J, Occlusal view of the bone defects. Note the three-wall defect morphology of the socket sites. K, L, Implants are placed in the ideal three-dimensional position to support on the fixed rehabilitation. M, Grafting using anorganic bovine bone mineral + autogenous bone harvested from the adjoining alveolar sites (50:50) to compensate bone remodeling and provide a more favorable bone and soft-tissue contour for esthetic reasons. Occlusal view of the grafted site. N, O, Clinical aspect 12 months after implant placement showing adequate peri-implant tissue stability and a newly fabricated prosthesis that enabled access for oral hygiene measures

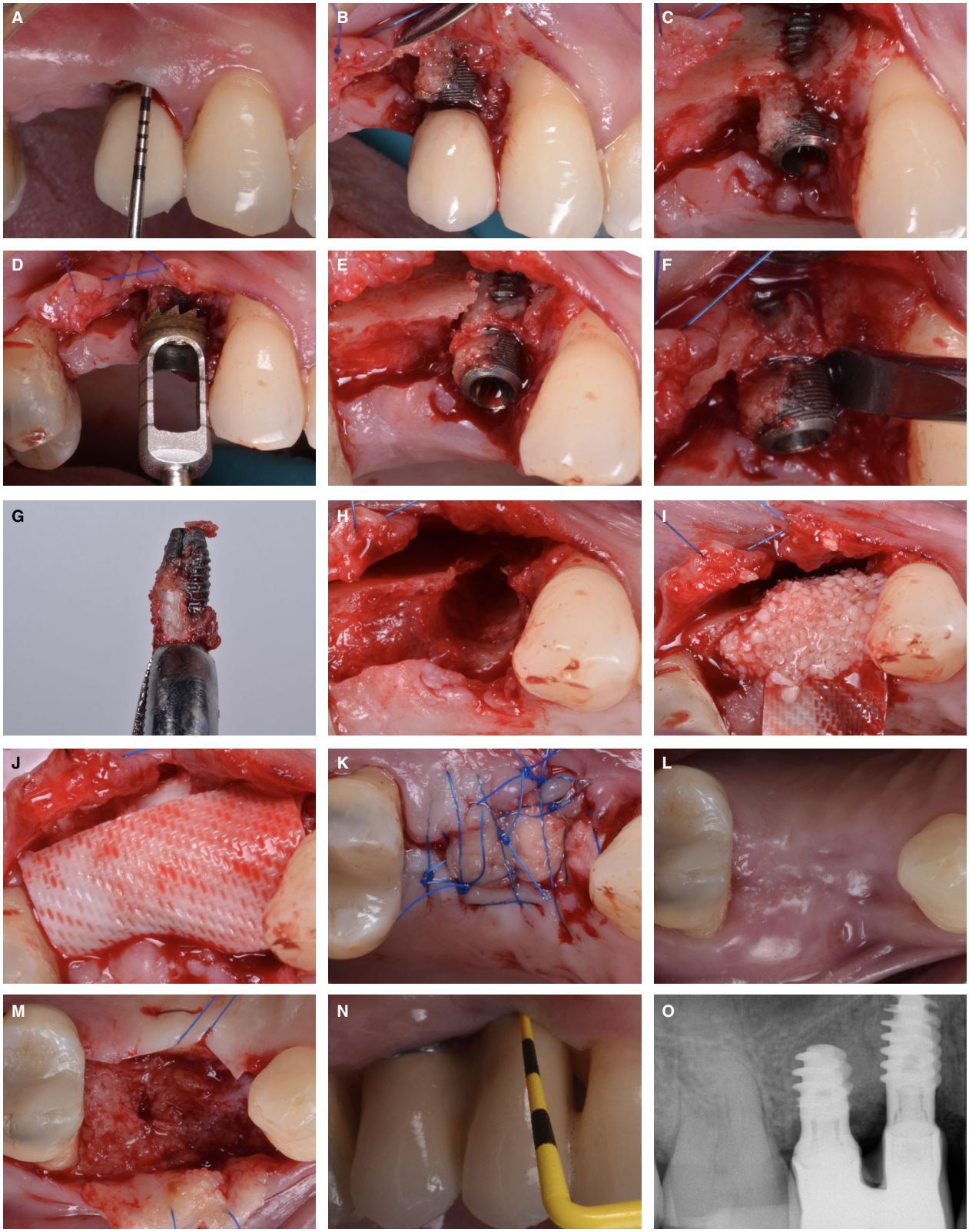


FIGURE 11 Implant placement at a previously failed site due to peri-implantitis. A, Clinical assessment indicated profuse bleeding on probing and increased probing pocket depth. B, C, Intraoperative view revealed bone loss and implant fenestration. D-G, Implant had to be removed by means of trephine, elevators, and forceps given the tight bone-to-implant contact present at the apical implant portion. H, Occlusal view of alveolar defect after implant removal. I-K, Simultaneous grafting was carried out to build up the alveolar bone structure by means of mineralized cortical cancellous allograft (Lifenet Health, Virginia Beach, VA, USA) and slowly resorbable membrane (Ossix Plus; Datum, Lod, Israel). L, M, Soft and hard-tissue healing 4 months after grafting revealed consistent structures for implant placement in the ideal three-dimensional position. N, Clinical and, O, radiographic outcomes at 18-month follow-up

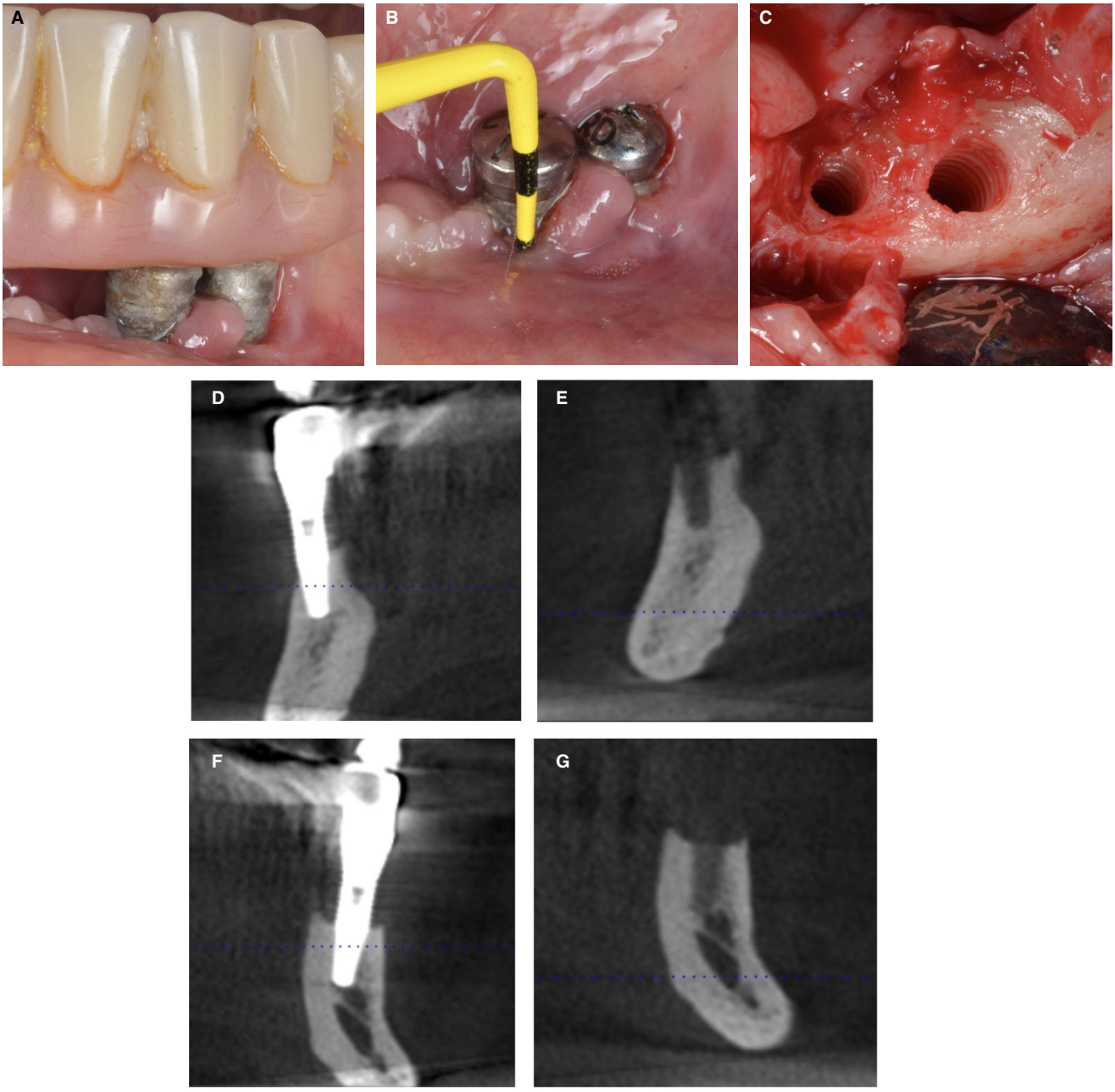


FIGURE 12 Spontaneous bone healing after atraumatic implant removal. A-C, Scenario of peri-implantitis exhibiting advanced bone loss in adjacent implants. D-G, Radiographic sections from implants prior to removal and 4 months after removal. Note the minimal bone remodeling

area, which is exposed to both vertical and horizontal movements that lead to bending overload.[57]

As mentioned previously, implant geometry, particularly a wider implant diameter, may provide more effective resistance to functional forces. In fact, it has been demonstrated that distinctive fracture loci can be identified according to implant width. Whereas fracture in the case of 5 mm implants may occur at the abutment neck, fracture in 3.3 mm implants tends to occur between the second (52%) and third threads (48%); such complications, therefore, are more difficult to manage.[58] A recent retrospective analysis of 2670 patients reported a relatively low risk of implant fracture (0.44%). It was demonstrated that implant fracture tends to occur 2-8 years following implantation. Five major risk factors have been identified. Specifically, titanium of a higher degree in purity lowers the risk of fracture by approximately 72%. Likewise, with every 1 mm increase in implant diameter, the risk of fracture decreases by approximately 96%. In contrast, factors such as bruxism, direct adjacency to cantilevers, and every 1 mm increase in implant length contribute to increase the likelihood of fracture by 18%-19%, 247%, and 22%, respectively.[59]

5.2 | Clinical management

In many cases, owing to an inability to remove the damaged component or the fractured implant, the use a trephine bur may be the only option for removal. In cases of fractured implants, submerging

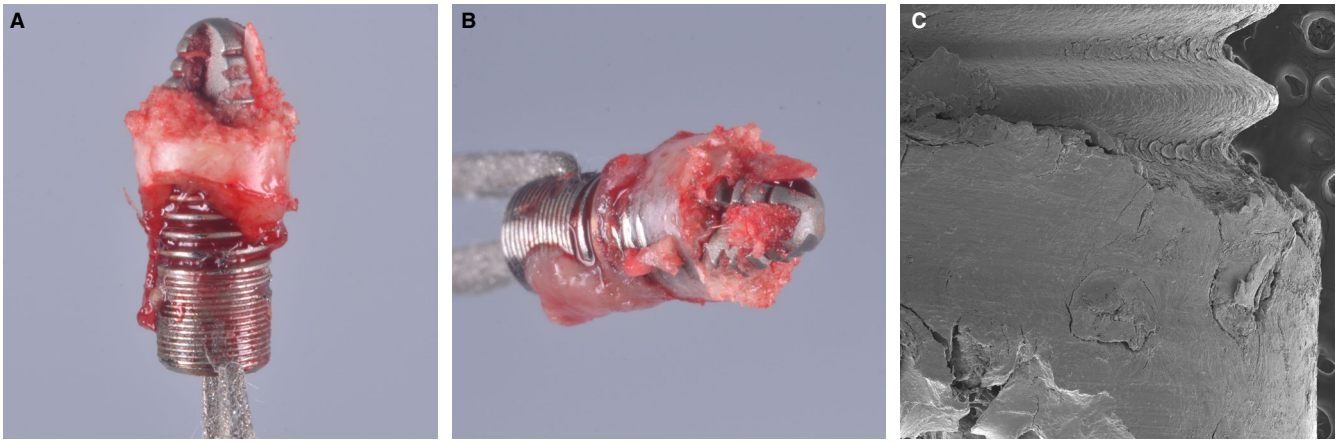


FIGURE 13 Implant removed using a trephine bur due to high degree of osseointegration at the apical portion of the implant. A, frontal view of the implant. B, lateral view. C. Scanning electron microscopy showing the interface between the osseointegrated implant and the exposed implant surface as consequence of moderate peri-implantitis [Colour figure can be viewed at wileyonlinelibrary.com]

the implant should be considered, as long as the contribution of the implant is negligible to oral rehabilitation. This option is particularly suited to scenarios where the implant surface is not contaminated, and it may be the preferred option in areas approaching anatomical boundaries, such as the inferior alveolar nerve or the maxillary sinus, in order to avoid possible injury during traumatic removal.

6 | METHODS FOR REMOVING DENTAL IMPLANTS

Various approaches and devices have been proposed to remove unsuccessful dental implants (Table 1).[60,61] Primitive methods included the use of a trephine bur or rotary low or high-speed burs under profuse irrigation, with the aim of resecting the failing implant en bloc with the surrounding alveolar bone by means of an ostectomy (Figure 7). These techniques are very invasive for the soft and hard tissues, and the risk of vascular damage is further increased, particularly in the case of mandibular implants. Hence, immediate implant placement in these scenarios is not advocated.

In the last 15 years, with the purpose of minimizing surgical invasiveness and to reduce morbidity and t simplify and shorten treatment, procedures based on breaking down the intimate contact between the implant and the bone through the application of shear stress have been advocated.[62-64] An example is localized resection via ultrahigh frequency piezosurgical instruments[65] or laser-assisted devices[66] that have demonstrated utility in removing failing dental implants. Nevertheless, these procedures are time consuming, and their invasiveness is debatable. More recently, other techniques have been proposed based on the application of a reverse torque (Figure 8).[62-64] The most straightforward approach involves a removal system that matches the implant internal or external connection and sits on top of the implant platform, which must be intact. Removal torque in a counterclockwise direction is exerted with a wrench in a perpendicular position (torque less than 200 N cm; Figure 8). If this technique proves unsuccessful, it has been proposed to screw a special instrument within the implant platform in clockwise direction reaching 50 N cm. Then, removal torque in the counterclockwise direction is exerted with a wrench in a perpendicular position (torque less than 250 N cm). Though this procedure is often sufficient (Figure 9). Otherwise, resecting 1-2 mm of the coronal (cortical) bone can improve the ease and success of implant removal using this technique. If none of these techniques is feasible due to a damaged implant connection, special burs made of tungsten carbide have been proposed to widen the implant connection and secure adequate fitting of the removing instrument (Figure 10). If these fail, more invasive techniques, such as the use of trephine burs and elevators, are advocated to efficiently remove failing implants (Figure 11).

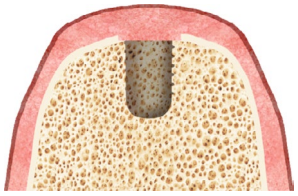
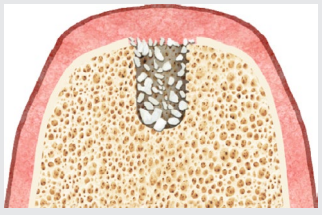
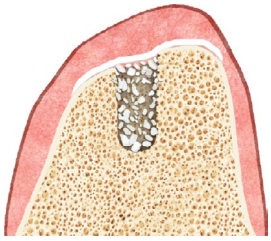
7 | BONE HEALING AT REMOVED IMPLANT SITES

Though the events that follow tooth extraction have been widely investigated in preclinical[22,23] and clinical trials,[67,68] the dimensional changes of the ridge and the healing events that follow implant removal remain poorly understood. Recently, a clinical study demonstrated that minimal (approximately 10%) hard tissue changes can be expected following implant removal due to peri-implantitis (Figure 12).[50] Simultaneous bone regeneration procedures and the use of a removal kit were shown to considerably reduce the impact upon the dimensional changes. A preclinical experimental study in sheep evaluated the biological sequelae after minimally invasive implant removal using a reverse torque (228 ± 18 N cm). Interestingly, it was possible to identify the Haversian and Volkmann canals running perpendicular to the implant axis 22 weeks after implantation. Regarding cellularity, osteocytes within lacunae were observed in close contact with the bone surface where the implants were retrieved. The morphology of these cells appeared normal, with no evidence of damage caused by the extraction.[62] Findings from this study suggested that immediate implant placement after removal is feasible from a biological perspective. Nevertheless, there remains

TABLE 2 Feasibility of implant placement after implant failure

		Second implant placement			
Author (year)	Study design	Patients (N)	Smoking (Y/N)	Failed implants (N)	Implant surface
Alsaadi et al (2006)[70]	Case series	41	Yes: 12 No: 29	58	Machined/TiUnite
Grossmann and Levin (2007)[73]	Retrospective cohort	28	Yes: 3 No: 25	31	Not reported
Machtei et al (2008)[48]	Retrospective cohort	56	Yes: 15 No: 41	79	Not reported
Machtei et al (2011)[74]	Case series		—	—	Medium roughness
Mardinger et al (2012)[75]	Retrospective cohort	144	Yes: 34 No: 110	144	Not reported
Kim et al (2010)[76]	Retrospective cohort	49	No: 49	60	Not reported
Wang et al (2015)[77]	Retrospective cohort	67	Yes: 12 No: 54	67	Sandblasted, large grit, acid-etched
Dimaira (2019)[78]	Prospective pilot study	14	Yes: 68.8% No: 22.2%	16	Porous tantalum

TABLE 3 Therapeutic alternatives for the management of the alveolar ridge after implant removal: spontaneous healing, bone grafting, and guided bone regeneration for ridge preservation

Therapeutic modality	Illustration	Advantages
Spontaneous healing		Spontaneous soft-tissue ingrowth Early implant placement (6-8 wk) Flapless approach Minimal invasiveness
Bone grafting		Attenuation of hard-tissue changes Flapless approachMinimal invasiveness
Guided bone regeneration or block grafting		Simultaneous alveolar bone preservation/gain

Grafting interventions	Time of second attempt implant placement	Implant survival (%)	Failure (%)	Time of failure (months)	Failure reason
Not reported	4-6	87.9	12.1	11.43 ± 6.7	Not reported
Not reported	5.8 ± 5.2	71	29	3.2 ± 2.3	Not reported
Lateral augmentation: 26; sinus augmentation: 6	6.75 ± 1.12	83.5	16.5	29.9 ± 2	Not reported
Not reported	10 ± 9.2	–	–	7.4 ± 9.5	Biological failure
N: 54%; guided bone regeneration: 39%; bone augmentation before replacement: 7%	4.8 ± 5.45	92.4	7.6	Early failure: 2 Late failure: 9	Failed osseointegration: 19%; overload: 9%; unknown: 72%
N: 28.3%; guided bone regeneration: 51.7%; bone-added osteotome sinus elevation: 28.3%; additional implant placement: 21.7%; bone graft: 70%	Immediate: 48.3% Delayed: 51.7% (2.40 ± 3.06)	88.3	11.7	Not reported	Not reported
N: 43; guided bone regeneration: 9; minor autogenous particle bone grafting: 4; trans-alveolar sinus lift: 7; trans-alveolar sinus lift + bone grafting: 4; lateral window sinus lift: 0	Immediate: 2 Delayed: 65	94.6	5.5	Early failure: 1 Late failure: 1	Uncontrolled infection and progressive bone loss
Graft: 12 N: 4	Immediate	93.8	6.2	Not reported	Not reported

Disadvantages	Clinical recommendations
Need for bone augmentation staged or simultaneous to implant placement	Corticotomies to promote bleeding and healing Secondary intention healing to promote spontaneous soft-tissue thickening and to gain keratinized mucosa at the crestal area
Late implant placement (>16 wk)	Corticotomies to promote bleeding and healing Use collagen sponge to stabilize the coagulum Secondary intention healing to promote spontaneous soft-tissue thickening and to gain keratinized mucosa at the crestal area
Flapped approach Technical demand Late implant placement (>16-32 wk) Invasiveness	Corticotomies to promote bleeding and healing Tension-free flap closure Soft-tissue conditioning might be needed at a second stage to gain keratinized mucosa

a need to explore the dynamic events and dimensional changes that take place after implant removal and how they affect the different implant placement protocols (Figure 13).

8 | IMPLANT OUTCOMES IN PREVIOUSLY FAILED SITES

As mentioned previously, implant placement protocols following implant removal should be tailored to the individual case scenario. In this respect, it is important to consider both soft (presence of attached mucosa) and hard-tissue (bone morphology) characteristics. The literature demonstrates that implant placement as a second (Table 2) or third attempt following implant failure (or implant removal) is feasible in terms of future implant survival.[69] A systematic review based on seven studies (five retrospective cohort clinical trials and two case series) found the survival rates following a second attempt to be approximately 88% over a mean follow-up of about 40 months.[69] The survival rate with a third attempt dropped by about 15% relative to the survival rate achieved with a second attempt. Interestingly, the major risk factors for implant survival/failure when attempting implantation after implant removal could be identified. For example, failure rates were higher in the maxilla (approximately 13%) than in the mandible (approximately 16%). Implant-supported single crowns were more likely to fail than fixed partial dentures. One study explored[70] the effect of surface modification (TiUnite; Nobel Biocare AG, Kloten, Switzerland) compared with machined-surface implants. Surprisingly, they reported that smokers did not yield higher failure rates than nonsmokers did.[69] The authors also observed that ridge augmentation was common practice in implant replacement (3%-70%) to compensate for bone loss prior to or after implant removal.[69] Recent systematic reviews have corroborated these findings.[71,72]

9 | CONCLUSIONS

1. Implant removal is now common practice in the dental setting. In order to minimize morbidity and offer alternative therapies to restore oral function and esthetics, minimally invasive implant removal techniques should be employed, if possible. Implant removal systems that utilize a reverse torque reduce damage to the soft and hard tissues compared with other methods.
2. Decision-making regarding the need for implant placement simultaneously to or following implant removal should be based on the need to satisfy prosthetic, biomechanical, and esthetic demands. The clinician should consider the genuine need for the proposed implant replacement to support or retain the prosthesis. This should routinely be proposed in the case of peri-implantitis, where significant bone loss might compromise straightforward implant placement.
3. Decision-making regarding the implant placement protocol should be tailored to the individual case scenario, considering both hard and soft-tissue characteristics (Table 3).
4. The nature of the biological events and dimensional changes that arise following implant removal remain poorly understood. Nevertheless, the clinical impression is that the lost surrounding bone is less vascular. Accordingly, and regardless of the procedure used for implant-site development or implant placement, corticotomies are encouraged to boost the healing potential.

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